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A Study of Charmonium Systems across the Deconfinement Transition *

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We present results from lattice studies of charmonium systems near the deconfinement transition temperature. On quenched isotropic lattices with lattice spacings between 0.02 and 0.05 fm, $\bar{q}q$ systems with quark masses close to the charm mass and with different spin-parity quantum numbers are studied in the temperature range $0.9T_c - 3T_c$. Results for temporal correlators of local operators, and the spectral functions constructed from them, are discussed. For the pseudoscalar and vector channels, the correlators are observed to change very little across the deconfinement transition, unlike in the case of the light quarks.

The behavior of charmonia across the deconfinement transition has been a subject of considerable interest ever since the breakthrough paper of Matsui and Satz [1]. Unlike light mesons, charmonia may exist as bound states even after the deconfinement transition. However, based on nonrelativistic arguments, Matsui and Satz predicted that already at temperatures close to transition, binding between quarks is reduced enough to dissolve J/ψ , and proposed its suppression as a signal of deconfinement. Several later studies, based on potential model calculations, predicted a pattern of dissolution, with the higher excitations dissolving earlier, and J/ψ dissolving at a temperature $\approx 1.1 T_c$ [2].

A more direct and reliable way to study the in-medium modifications of charmonia is to study on lattice the finite temperature imaginary time correlators

$$G_H(\tau, \vec{p}, T) = \langle J_H(\tau, \vec{p}) J_H^\dagger(0, -\vec{p}) \rangle_T \quad (1)$$

where J_H is the suitable mesonic operator, projected on the state with spatial momentum \vec{p} . For zero temperature studies, one often uses smeared operators to get a good overlap with the ground state. However, since we are interested in study-

ing whether the bound states exist or not, using smeared operators is not a good idea since it can mimic bound states [3]. We therefore use point-to-point correlators, and study the temporal correlators, Eq. (1), with $J_H = \bar{c}c$, $\bar{c}\gamma_5 c$, $\bar{c}\gamma_\mu c$ and $\bar{c}\gamma_\mu\gamma_5 c$ to explore the 3P_0 (χ_{c0}), 1S_0 (η_c), 3S_1 (J/ψ) and 3P_1 (χ_{c1}) channels, respectively. For this study we use only quenched lattices, and used the nonperturbatively improved [4] clover action for the quarks. Our lattice parameters are given in Table 1. The lattice operators are connected to the continuum operators as $J_H^{\text{Cont}} = Z_H f_\kappa^2 J_H^{\text{Lat}} a^{-3}$, where $f_\kappa = \sqrt{2\kappa(1 + a\tilde{m}_0)}$ is the quark renormalization factor for massive quark with tadpole improved bare quark mass $a\tilde{m}_0 = (1/2\kappa - 1/2\kappa_c)/u_0$. Z_H is obtained from tadpole improved perturbation theory in the massless limit [5].

Table 1

Lattice parameters. The lattice spacing is obtained from the string tension.

β	$a^{-1}(\text{GeV})$	Size	T/T_c	#conf
6.499	4.042	$48^3 \times 16$	0.93	50
6.499	4.042	$48^3 \times 12$	1.25	50
6.499	4.042	$48^3 \times 10$	1.5	46
6.640	4.860	$48^3 \times 12$	1.5	60
7.192	9.720	$48^3 \times 12$	3.0	90

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For our coarsest lattices, we have three temperatures at the same lattice spacing. We use two κ values, 0.1300 and 0.1234, which bracket the charm quark mass. We estimate the zero temperature masses of the corresponding mesons from the spatial correlators at $0.93T_c$. This is permissible since the spatial correlators correspond to zero-temperature correlators for a lattice with an extent of ≈ 0.9 fm in one of the spatial directions, which is much larger than the typical size of a charmonium. (In fact, even for the much larger light mesons, the spatial correlators at this temperature have been found to reproduce the zero temperature masses quite well [6].) The masses we get are given in Table 2. By linear interpolation, we estimate that $\kappa_{\text{charm}} \approx 0.1280$ for this lattice.

Table 2

Masses (in GeV) of the different representations obtained from the spatial correlators.

κ	Mass (in GeV)			
	η_c	J/ψ	χ_{c0}	χ_{c1}
0.1300	2.44(1)	2.52(1)	2.90(3)	2.99(3)
0.1234	4.26(1)	4.30(1)	4.73(5)	4.76(5)

Fig. 1 shows the temporal correlators for the different channels, for $\kappa = 0.1300$. To highlight the difference from free quark propagation, we have divided the correlators by the corresponding free correlators, with same bare quark mass (in lattice units) as the tadpole improved bare quark mass of the interacting case. Fig. 1 shows that the scalar and axial vector channels are considerably modified on crossing T_c . In the pseudoscalar and vector channels, on the other hand, there is very little change between $0.93 T_c$ and $1.5 T_c$.

Further insight can be obtained from looking at the spectral function at each temperature. The spectral function $\sigma(\omega)$ is connected to the imaginary time correlator $G(\tau)$ by the integral equation

$$G(\tau) = \int_0^\infty d\omega \sigma(\omega) \frac{\cosh(\omega(\tau - 1/2T))}{\sinh(\omega/2T)}. \quad (2)$$

(Here we consider only states projected to zero spatial momentum.) The severely underconstrained problem of reconstruction of the spectral

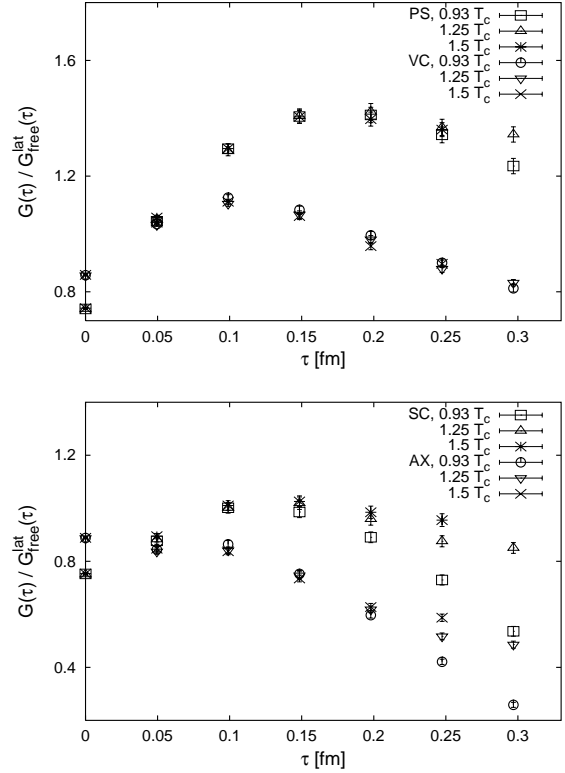


Figure 1. Temporal correlators for the different channels (top: pseudoscalar and vector; bottom: scalar and axial vector) at $\beta = 6.499$, for $\kappa = 0.1300$.

function from the information of the correlator at finite number of points can be handled using the maximum entropy method. At zero temperature this method has been successfully applied [7]. At finite temperature, this method was also applied in the light quark sector [3]. We follow here the methods of Ref. [3]. The spectral functions for the pseudoscalar and axial vector channels are shown in Fig. 2. While the axial vector peak below T_c in Fig. 2 has completely disappeared above T_c , the pseudoscalar bound state peak persists at $1.25 T_c$, with an essentially unchanged position, though somewhat broadened. The vector channel shows very similar behavior to the pseudoscalar one, with the peak persisting at $1.25 T_c$, while the scalar channel behavior is very similar to the axial vector one. The pseudoscalar and vector peaks also seem to survive at $1.5 T_c$, though finer lat-

tices are needed at these and higher temperatures to have a reasonably large number of points in the temporal direction. The behavior of the different channels is very similar in the $\kappa = 0.1234$ case, the scalar and axial vector channel peaks disappearing already at $1.25 T_c$ while the pseudoscalar and vector peaks surviving beyond this temperature. Since these two values of κ bracket the charm, we conclude that for physical charm, while the 1P states χ_{c0} and χ_{c1} are dissolved, the 1S states J/ψ and η_c survive as bound states at temperatures up to $1.5 T_c$.

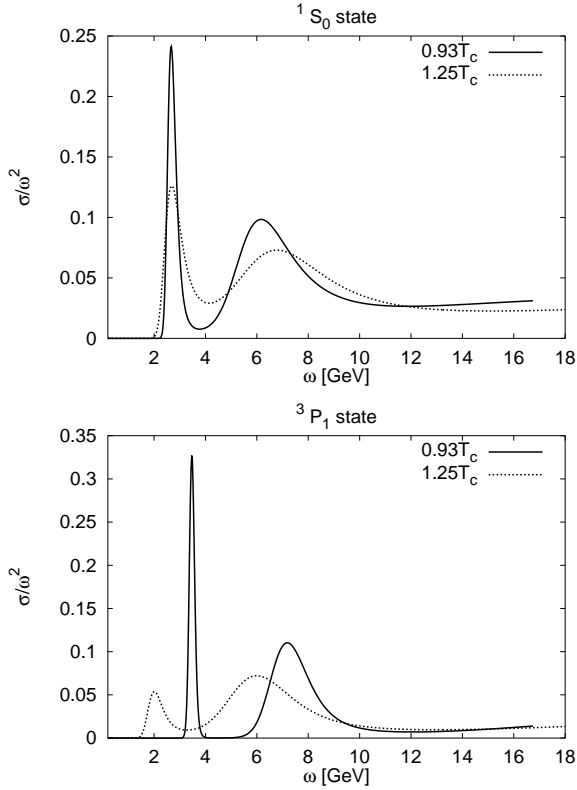


Figure 2. Spectral functions for the pseudoscalar (top) and axial vector (bottom) channels at 0.93 and $1.25 T_c$. A detailed error analysis will be presented elsewhere.

At the finer lattices listed in Table 1, we at present have only one temperature at each lattice spacing. So we need to estimate κ for each case. We choose the κ to give the same (tadpole-improved) bare quark mass, in physical units, as

the κ_{charm} obtained at $\beta = 6.499$. This way, we estimate $\kappa = 0.1290$ at $\beta = 6.64$ (for our $1.5 T_c$ run) and $\kappa = 0.13114$ at $\beta = 7.192$ (the $3 T_c$ run). The data at $1.5 T_c$ supports the results of the coarser lattice at the same temperature. However, since we can not estimate the systematic error involved in our estimate of κ , more precise conclusion cannot be attained at present. We are now generating results at $1.1 T_c$ for $\beta = 6.64$ and at $1.5 T_c$ at $\beta = 7.192$. This will enable us to do a more detailed analysis of the results at these finer lattices.

To summarize, we conduct a study of the behavior of $\bar{c}c$ bound states across the deconfinement transition by looking at the suitable correlators and the spectral functions reconstructed from them. Our studies support the sequential pattern for charmonium dissolution obtained from potential model studies, where the broader bound states (the scalar and axial vector channels) dissolve before the pseudoscalar and vector channels. The pseudoscalar and vector channels are seen to survive as bound states still at $1.25 T_c$, and probably dissolve after $1.5 T_c$. Results of direct lattice studies of charmonia systems have also been presented by M. Asakawa and K. Nomura in this conference [8]. Our conclusions are consistent with theirs.

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